

WHAT IS CLAIMED IS:

1. Apparatus for determining mass flow rate of a fluid in a flow passage having a predetermined area, comprising

a sensor including a waveguide disposed in the flow passage and having a section exposed to the fluid flowing in the passage;

means in the flow path for shedding vortices;

an exciter for propagating an ultrasonic wave along said waveguide including along said section and having a propagation velocity dependent upon the density of the fluid adjacent said section;

first means coupled to said waveguide for detecting the propagated wave and providing a first output signal proportional to the transit time of the propagated wave along the density-responsive section of the waveguide for determining the density of the fluid;

second means forming part of said sensor for detecting the shedding frequency of the vortices shed from said vortex shedding means and providing a second output signal proportional thereto for determining the velocity of the fluid; and

a processor for generating an indication of the mass flow rate of the fluid through the passage based on the first and second signals and the predetermined area of the flow passage.

2. Apparatus according to claim 1 wherein said first means detects density-responsive signals of the propagated wave at a frequency greater than the shedding frequencies.

3. Apparatus sensor according to claim 2 wherein said detected density-responsive signals are at a frequency of 20 kHz or more and the shedding frequencies are 10 kHz or less.

4. Apparatus according to claim 3 wherein said vortex shedding means includes said waveguide section; said second means being coupled to said waveguide for sensing torque in said waveguide in response to vortices shed from the waveguide section.

5. Apparatus according to claim 1 wherein said vortex shedding means includes a sheath surrounding said waveguide section.

6. Apparatus according to claim 5 wherein said sheath has a first aperture for receiving density representative portions of said fluid for flow about said waveguide section and a second aperture for flowing fluid from within the sheath into the flow stream.

7. Apparatus according to claim 1 wherein said second means includes a transducer for directing an acoustical beam through vortices downstream of the waveguide and a receiver for detecting modulation of the phase or amplitude of the acoustical beam and providing said second output signal proportional to the shedding frequency of the vortices for determining the velocity of the fluid.

8. Apparatus according to claim 1 wherein said second means includes a transducer on one side of the flow passage for transmitting an ultrasonic beam, a reflector on an opposite side of the flow passage for reflecting the beam and a receiver for detecting modulation of the phase or amplitude of the reflected beam, said beam including a first beam portion from said transducer to said reflector lying upstream of the waveguide and a second

beam portion from the reflector to the second receiver and passing through the shed vortices to provide a second output signal proportional to the shedding frequency of the vortices for determining the velocity of the fluid.

9. Apparatus according to claim 1 wherein said second means includes means for measuring the change in sign of the circulation of the shed vortices to provide said second output signal proportional to the velocity of the fluid.

10. Apparatus according to claim 1 wherein said exciter propagates ultrasonic waves along one segment of the waveguide section in flexure, said first means detecting signals that include a flexural wave contribution, and means for separating said contribution from the total transit time, and providing said first output signal to determine the fluid density.

11. Apparatus according to claim 1 wherein said exciter propagates ultrasonic waves along the waveguide section in flexure, said first means detecting the flexural wave and providing said first output signal to determine the fluid density wherein said flexural waves have major frequency components in the inaudible ultrasonic band above 20 kHz and below 200 kHz.

12. Apparatus according to claim 10 wherein said vortex shedding means includes two bluff shapes facing in opposite axial directions to shed vortices for bidirectional flow.

13. Apparatus according to claim 1 wherein said shedding frequency lies between about 100 Hz and 10 kHz, said exciter propagating torsional waves along said waveguide section in an inaudible frequency band at least ten times higher in frequency than said shedding frequency.

14. Apparatus according to claim 1 wherein the fluid flow passage comprises an axially extending pipe, said sensor including a wafer body installed in said pipe and having an axial length not in excess of about five times the nominal pipe size and up to about three times the internal diameter of said wafer body.

15. Apparatus according to claim 1 wherein said fluid flow passage comprises an axial extending pipe and said waveguide extends across the pipe occupying 10% or less of the flow area of the pipe.

16. Apparatus according to claim 1 wherein said vortex shedding means includes said waveguide section, said second means being coupled to said waveguide for sensing torque in said waveguide in response to vortices shed from the waveguide section, said second means including a transducer for directing an acoustical beam through vortices downstream of said waveguide and a receiver for detecting modulation of the phase or amplitude of the acoustical beam to provide an additional output signal proportional to the frequency of the shed vortices for determining the velocity of the fluid, the second output signal and the additional output signal serving as a cross-check on the accuracy of the velocity determination.

17. Apparatus according to claim 1 wherein said waveguide includes at least one impedance transformation utilizing two or more tapers disposed symmetrically about the axis of the waveguide.

18. Apparatus according to claim 1 wherein said ultrasonic wave does not substantially couple to acoustic noise in the fluid.

19. A method for determining mass flow rate of a fluid in a flow passage having a predetermined area, comprising the steps of:

providing a waveguide disposed in the flow passage with a section exposed to the fluid flowing in the passage;

providing a vortex shedder in the flow path for shedding vortices;

propagating an ultrasonic wave along said waveguide including along said section having a propagation velocity dependent upon the density of the fluid adjacent said section;

detecting the propagated wave;

providing a first output signal proportional to the transit time of the detected propagated wave along the density-responsive section of the waveguide for determining the density of the fluid;

detecting the frequency of the vortices shed from said vortex shedder;

providing a second output signal proportional to the detected shedding frequency for determining the velocity of the fluid; and

generating an indication of the mass flow rate of the fluid through the passage based on the first and second signals and the predetermined area of the flow passage.

20. A method according to claim 19 including detecting density-responsive signals of the propagated wave at a frequency greater than the shedding frequencies.

21. A method according to claim 20 including detecting the density-responsive signals at a frequency of 20 kHz or more and detecting shedding frequencies of 10 kHz or less.

22. A method according to claim 19 including propagating torsional waves along said waveguide section and sensing torque in said waveguide in response to vortices shed from the waveguide section.

23. A method according to claim 19 including providing a sheath surrounding said waveguide section for shedding the vortices.

24. A method according to claim 23 including providing a first aperture in said sheath for receiving density representative portions of said fluid for flow about said waveguide section and providing a second aperture in said sheath for flowing fluid from within the sheath into the flow stream.

25. A method according to claim 19 including directing an acoustical beam through vortices downstream of the waveguide, detecting a modulation of the phase or amplitude of the acoustical beam and providing said second output signal proportional to the shedding frequency of the vortices for determining the velocity of the fluid.

26. A method according to claim 19 including transmitting an ultrasonic beam across the flow passage upstream of the waveguide, reflecting the beam across the flow passage downstream of the waveguide through the vortices to a receiver, and detecting a modulation of the phase or amplitude of the reflected beam.

27. A method according to claim 19 including measuring a change in sign of the circulation of the shed vortices to provide said second output signal proportional to the velocity of the fluid.

28. A method according to claim 19 including propagating ultrasonic waves along the waveguide section in flexure, detecting the flexural waves and providing said first output signal in response to said detection to determine the fluid density.

29. A method according to claim 19 including propagating an ultrasonic wave of the lower order along said waveguide.

30. A method according to claim 19 including propagating an ultrasonic wave which does not radiate compressional waves to any significance into the fluid adjacent said waveguide.